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CONDITION MONITORING AND FAULT DIAGNOSIS OF INDUCTION MOTORS

A PROJECT REPORT

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BONAFIDE CERTIFICATE

This is to Certify that this thesis titled "**CONDITION MONITORING AND FAULT DIAGNOSIS OF INDUCTION MOTORS**" is the bonafide work of

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ABSTRACT

Condition monitoring and fault diagnosis of induction motors has been a challenging task for engineers and researchers in many industries. Current monitoring techniques are usually applied to detect various induction motor faults such as stator winding faults, bearing faults etc. This is because the basic electrical quantities associated with electromechanical parts such as current and voltage are readily measured by tapping into the existing system of voltage and current transformers that is always installed as a part of protection system. Time domain and frequency domain analysis techniques using MATLAB has been implemented in order to categorize the faults. The logical next step after condition monitoring is fault diagnostics and automated communication of the type of fault to a remote device. This thesis presents a cost effective and efficient solution for this purpose with a help of Arduino microcontroller and GSM based communication module. Arduino provides an open source programming platform wherein n number of libraries can be added by the user. Minimum power consumption, simple and clear programming language, cost efficiency, open source with extensible hardware and software being its key features. Global System for Mobile Communications has a limited transmission power of 2 watts in GSM 850/900 and 1 watt in GSM 1800/1900. The GSM technology has a wide bandwidth and uses five bands of MHz frequency; 450, 850, 900, 1800 and 1900 MHz .Those handsets can then switch between those frequencies automatically as needed, in order to maintain a network connection almost anywhere. The signals available with GSM service are efficient, meaning that a great deal of data can transmit across the frequency bands without reducing the effectiveness of the signals.

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CHAPTER 1

INTRODUCTION

1.1 GENERAL

Condition monitoring and fault diagnosis of induction motors has been a challenging task for engineers and researchers in many industries. Condition monitoring is defined as the continuous evaluation of equipment's life throughout its service life. It is important to able to detect faults when they are developing and these are called incipient failures. This system allows machine operator to have necessary spare parts before the machine is stripped down thereby reducing outage times. Current monitoring techniques are usually applied to detect various induction motor faults such as stator winding faults, bearing faults etc. This is because the basic electrical quantities associated with electromechanical parts such as current and voltage are readily measured by tapping into the existing system of voltage and current transformers that is always installed as a part of protection system.

In fixed frequency, low voltage mains fed induction motors, it is generally accepted that there is normally no forewarning of insulation degradation. The first indication of the problem will be that a fault actually develops. Pre-warning of motor failure can only be achieved in shorted turns which can initially be diagnosed via on-line diagnostic techniques. This requires continuous online monitoring to diagnose the faults for induction motors. There is also a question of how long it takes for the shorted turns within a coil in low voltage stator winding to develop a phase to phase fault or phase to earth fault. There is not a simple qualitative answer to that question since it will be a function of many variables and ill in fact be unique to each motor. Time domain and frequency domain analysis techniques using MATLAB has been implemented in order to categorize the faults.

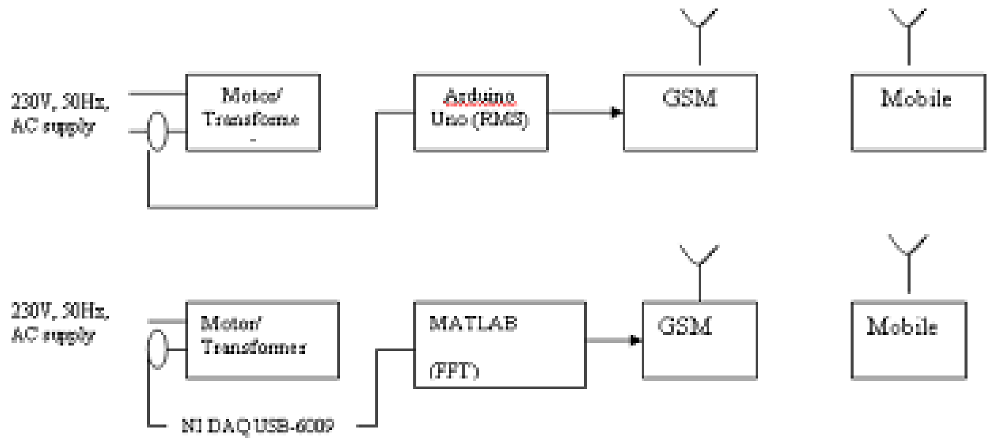

Fig 1: Fundamental Block Diagram

The logical next step after condition monitoring is fault diagnostics and automated communication of the type of fault to a remote device. This thesis presents a cost effective and efficient solution for this purpose with a help of Arduino microcontroller and GSM based communication module. Arduino provides an open source programming platform wherein n number of libraries can be added by the user. Minimum power consumption, simple and clear programming language, cost efficiency, open source with extensible hardware and software are its key features. GSM (Global System for Mobile Communications), is a standard set developed by the European Telecommunications Standards Institute (ETSI) to describe protocols for second generation digital cellular networks used by mobile phones. The transmission power in the handset is limited to a maximum of 2 watts in GSM 850/900 and 1 watt in GSM 1800/1900. The GSM technology has a wide bandwidth and uses five bands of MHz frequency; 450, 850, 900, 1800 and 1900 MHz Those handsets can then switch between those frequencies automatically as needed, in order to maintain a network connection almost anywhere. The signals available with GSM service are efficient, meaning that a great deal of data can transmit across the frequency bands without reducing the effectiveness of the signals. GSM providers control a large share of the cellular market and therefore are able to provide a large variety of affordable services.

1.2 Literature survey

A thesis on condition monitoring and fault diagnosis of induction motors using motor current signature analysis by Neelam Mehala has discussed that fault frequencies that occur in motor current spectra are different for different motor faults. These fault frequencies can be easily detected with the help of Motor Current Signature Analysis (MCSA). This proposed method in research allowed continuous real time tracking of various types of faults in induction motors operating under continuous stationary and non-stationary conditions. The effect of these faults on motor current spectra was investigated through experiments wherein an experimental setup was designed that can accurately repeat the measurements of current signals.

The paper on A Survey of Methods for Detection of Stator-Related Faults in Induction Machines provide a survey of existing techniques for detection of stator-related faults, which include stator winding turn faults, stator core faults, temperature monitoring and thermal protection, and stator winding insulation testing. The root causes of fault inception, available techniques for detection, and recommendations for further research are presented.

Online and Remote Motor Energy Monitoring and Fault Diagnostics by Lu et al(2008) identifies the synergies between wireless sensor networks (WSNs) and nonintrusive electrical-signal-based motor signature analysis and proposes a scheme of applying WSNs in online and remote energy monitoring and fault diagnostics for industrial motor systems. The main scope is to provide a system overview where the nonintrusive nature of the electrical signal-based motor signature analysis enables its applications in the selected communication mode. Special considerations in designing nonintrusive motor energy monitoring and fault diagnostic methods in such systems are discussed.

1.3 OBJECTIVE OF THE THESIS

The project aims at providing early warning of a fault from the frequency anomalies of measured parameters based on the measurements made from an electrical motor. The event of an occurrence of fault has to be communicated in order to build an efficient condition monitoring system.

1.4 ORGANISATION OF THE THESIS

Chapter 1 Introduction of the thesis with presentation on Literature Survey.

Chapter 2 Focus on Condition Monitoring and Fault Diagnosis techniques for different faults occurring in an induction motor.

Chapter 3 speaks about the advantages of communication techniques that can be implemented to inform the remote device.

Chapter 4 gives the conclusion.

CHAPTER 2

CONDITION MONITORING AND FAULT DIAGNOSTICS

2.1 GENERAL

Fault diagnosis is a determination of specific fault that has occurred in system. A typical condition monitoring and fault diagnosis process usually consists of four phases as shown in the Fig 2.

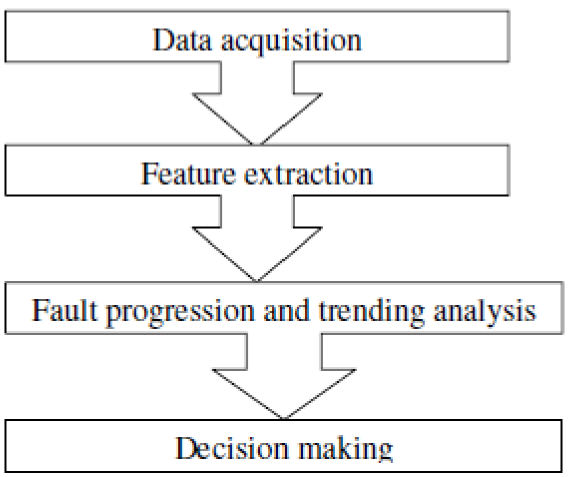

Fig 2: A typical condition monitoring and fault diagnosis process

2.2 MOTOR CURRENT SIGNATURE ANALYSIS

Various studies have addressed the application of motor current signature analysis for the detection of incipient fault in induction motors. It investigates the efficacy of current monitoring for bearing fault detection by correlating the relationship between vibration and current frequencies caused by incipient bearing failures. These failures are reviewed and the characteristic frequencies associated with the physical construction of bearings are defined. The effects on the stator current spectrum are described and related frequencies are determined. Experimental results which show the vibration and the current spectra of an induction motor with different faults are used to verify the relationship between vibrational and current frequencies. The test results clearly illustrate that the stator current signature can be used to identify the presence of fault. It has been learnt that a characteristic spectral component of the current appears directly at the frequency disturbance which is important in automated diagnostic systems wherein irrelevant frequency components those at multiples of supply frequency, are screened out.

Some of the benefits of MCSA include non-intrusive detection technique, remote sensing capability and safety to operate. These can be achieved with the help of current sensors that can be placed anywhere on the electrical supply line without jeopardizing the signal strength and performance.

2.3 ANALYTIC TECHNIQUES

2.3.1 TIME DOMAIN ANALYSIS

The RMS value of the vibration signal is used for primary investigation of the machine health. The RMS values of the machine voltages and currents are used to detect the unbalanced supply conditions, and to differentiate its effect from the effect of the other types of fault. RMS or quadratic mean is a statistical measure of the magnitude of a varying quantity. It is especially useful when variants are positive and negative like sinusoids. The name comes from the fact that it is the square root of the mean of the squares of the values.

$$RMS = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i)^2} \qquad (1)$$

The root mean square (RMS) value of a current signal is a time analysis feature, which is measure of the power content in the current signature. This feature is good for tracking the overall noise and current level, but it will not provide any information on which component is failing.

2.3.2 FREQUENCY DOMAIN ANALYSIS

The classical method for signal analysis the frequency domain is the estimation of the PSD based on the discrete FT of the signal x. the PSD indicates the distribution of signal energy with respect to frequency. The common estimation method for the PSD is the periodogram $P_{xx}(f)$, which is defined as the square of the signal's N-point FT divided by N as in eq. (2).

$$P_{xx}(f) = \frac{1}{N}\left|\sum_{n=0}^{N-1} x(n)e^{-j2\pi fn}\right|^2 \qquad \ldots \qquad \mathbf{(2)}$$

2.4 EXPERIMENTAL DIAGNOSIS OF FAULTS USING PEROIDOGRAM MEAN SQUARE POWER SPECTRUM

The MCSA is applied for the detection of faults where the side bands around the fundamental frequency indicate the presence of fault in a motor. Based on MCSA, a system for fault detection was designed. The current samples of the faulted motor are acquired and these are then transformed to the frequency domain using a power spectrum algorithm. The frequency spectrum is calculated and analyzed aiming to detect specific fault frequencies related to incipient faults. For each fault, there is an associated frequency that can be identified in the spectrum. Faults are detected comparing the harmonic amplitude of specific frequencies with the harmonic amplitude of the same machine as healthy. Based on the amplitude in dB it is also possible to determine the degree of faulty condition.

2.5 CURRENT SENSOR

Fig 3: Current sensor SCT-013

The current monitor used here is a non-invasive AC current sensor (30A max), Model SCT-013-000 built based on split core current transformer (ferrite core). It has no internal burden resistor, but zener diodes limit the voltage that may appear on the plug and across the windings to a safe value should the transformer be unplugged from the transmitter/instrument and the burden whilst the primary is energized. It is capable of developing sufficient voltage to fully drive a 5 V input. It is characterized by open size 13 mm x 13 mm with a 1m leading wire.

INPUT CURRENT	0-30 A
OUTPUT VOLTAGE	0-1 V
NON LINEARITY	± 1%
TURN RATIO	1800:1
WORK TEMPERATURE	-25° C to 70° C

Table 1: Specifications of SCT-013 current sensor

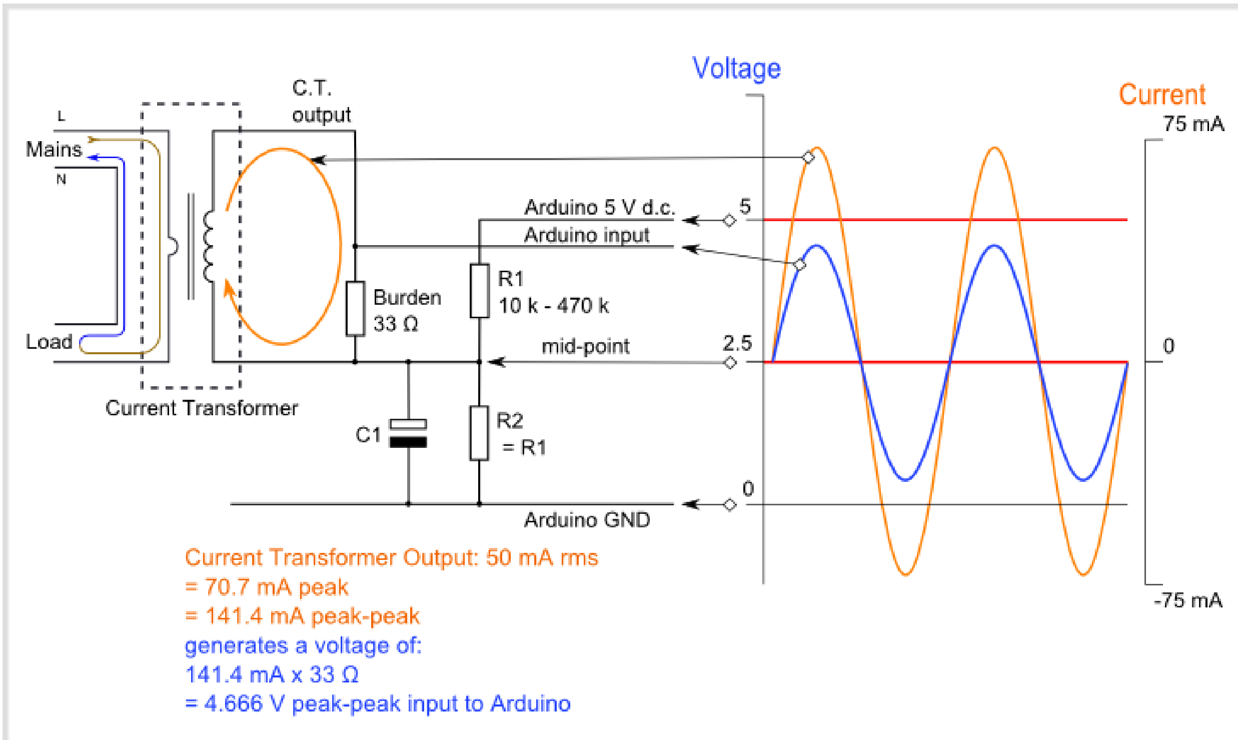

Fig 4: Circuit configuration for current sensor

SELECTION OF BURDEN RESISTANCE

The YHDC SCT-013-000 CT has a current range of 0 to 30 A so for this example 100 A is considered as our maximum current.

Primary peak-current = RMS current × √2 = 100 A × 1.414 = 141.4

The YHDC SCT-013-000 CT has 1800 turns and so the secondary peak current will be Secondary peak-current= Primary peak current/ no. of turns = 141.4 A / 1800=0.7855A

For an Arduino running at 5V, AREF / 2 becomes 5 V / 2 = 2.5 V and so the ideal burden resistance is given by

Ideal burden resistance = (AREF/2)/Secondary peak-current= 2.5V / 0.07855A =31.82 Ω. It is not a common resistor value hence 33 Ω ±1% is chosen.

2.6 STATOR WINDING FAULT ANALYSIS

The inter-turn short circuit of the stator winding is the starting point of winding faults and it creates turn loss of phase winding. The short circuit current flows in the in the inter-turn short circuit windings. This initiates a negative mmf which reduces the net mmf of motor phase. Therefore, the waveform air gap flux, which is changed by the distortion of net mmf, induces harmonic frequencies in stator winding current. The frequencies appear in the spectrum according to the following equation

$$f_{sc} = f_1 \left\{ k \pm \frac{n}{p}(1-s) \right\}$$

where p-pole pairs

s-rotor slip

k-1, 3, 5..

n-integer 1,2,3..

Execution of the MATLAB code as per Annexure-1 generates the following synthetic signal as shown in the plot. The sideband frequencies of this plot is checked if it matches with the estimated sideband frequency of windings short fault through a set of well-defined algorithm upon extraction of those frequency components.

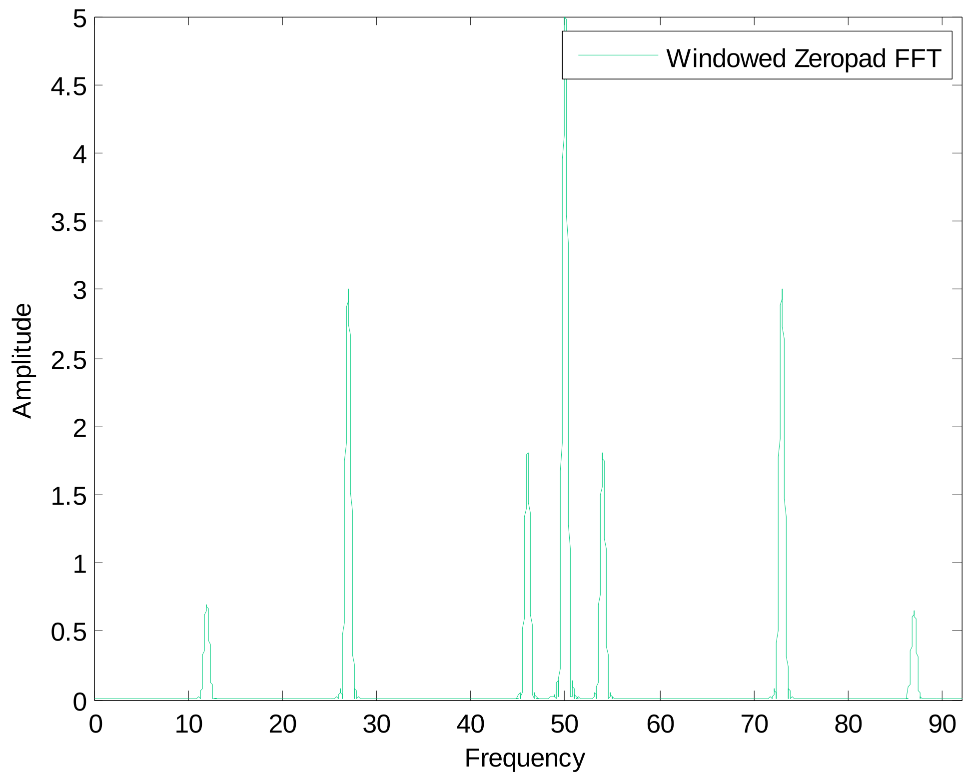

Fig 5 : Synthetic signal's windowed zeropad FFT for stator winding fault

LOAD CONDITONS	**SLIP**	**LSB**	**USB**
No load	0.01	25	75

Table 2 : Expected fault frequencies for a given slip at a given load condition for stator winding faults

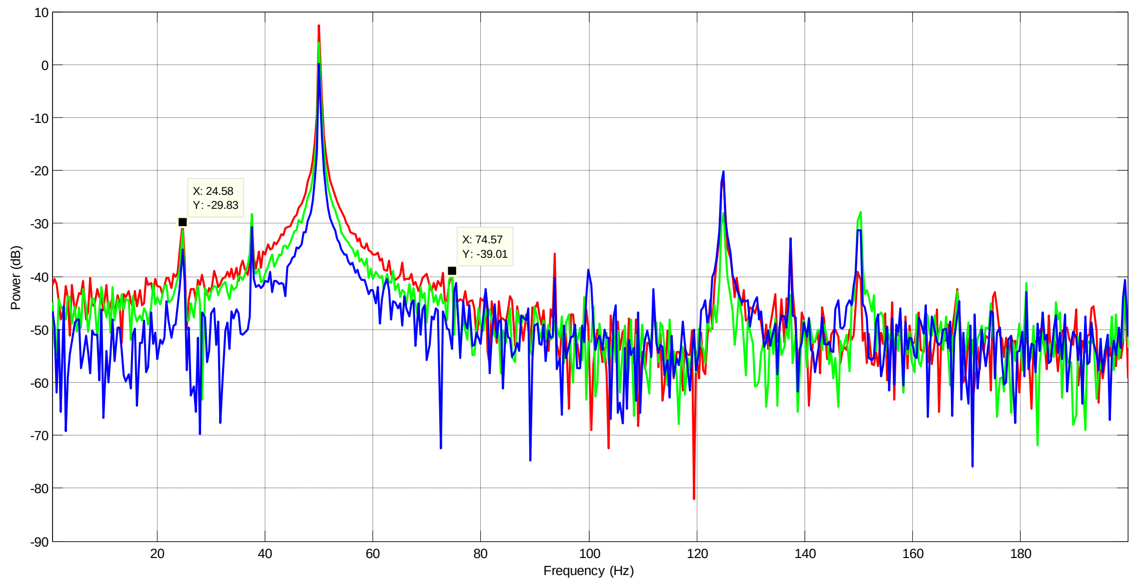

Fig 6 : Plot for data obtained from faulted motor

2.6 BROKEN ROTOR BAR ANALYSIS

Broken rotor bars do not initially cause induction motor to fail but there can be serious secondary effects of broken rotor bar. The broken parts of rotor bar hits to the stator core of a high voltage motor at high velocity. This can cause serious mechanical damage to the insulation and a consequential winding failure may follow, resulting in a costly repair and lost production.

Advanced signal processing techniques in combination with advanced computerized data processing and acquisition show new ways in the field of rotor bar analysis monitored by use of spectral analysis. The success of these techniques depends upon locating by spectrum analysis with specific harmonic components caused by faults. Due to broken bars, two slip frequency sideband near the main harmonic appeared. Usually a decibel versus frequency spectrum is used in order to detect the unique current signature patterns that are characteristics of different faults. The rotating magnetic field induces rotor voltages and current at slip frequency with regard to the rotor. If rotor asymmetry occurs then there will be a resultant backward rotating field at slip frequency with respect to the forward rotating motor. The backward rotating field induces a voltage in the stator at a corresponding frequency. Thus a related current which modifies the stator current spectra also appears. Therefore, twice slip frequencies sideband occurs at $\pm 2sf_1$ both sides of the supply frequency.

$$f = f_1\ (1 \pm 2s)$$

Execution of the MATLAB code as per Annexure-1generates the following synthetic signal as shown in the following plot. The sideband frequencies of this plot is checked if it matches with the estimated sideband frequency of broken rotor bar fault through a set of well-defined algorithm upon extraction of those frequency components.

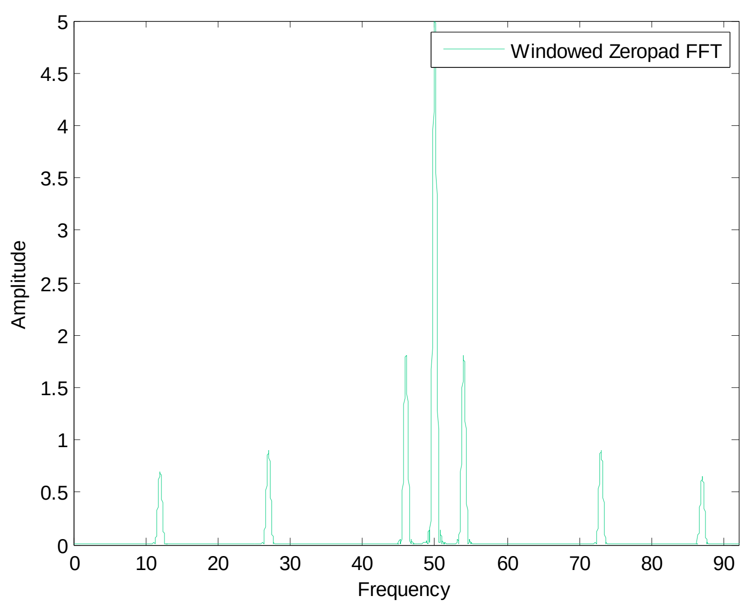

Fig 7: Synthetic signal’s windowed zeropad FFT for broken rotor bar fault

LOAD CONDITONS	**SLIP**	**LSB**	**USB**
Half load	0.04	46	54

Table 3: Expected fault frequencies for a given slip at a given load condition for broken bar rotor faults

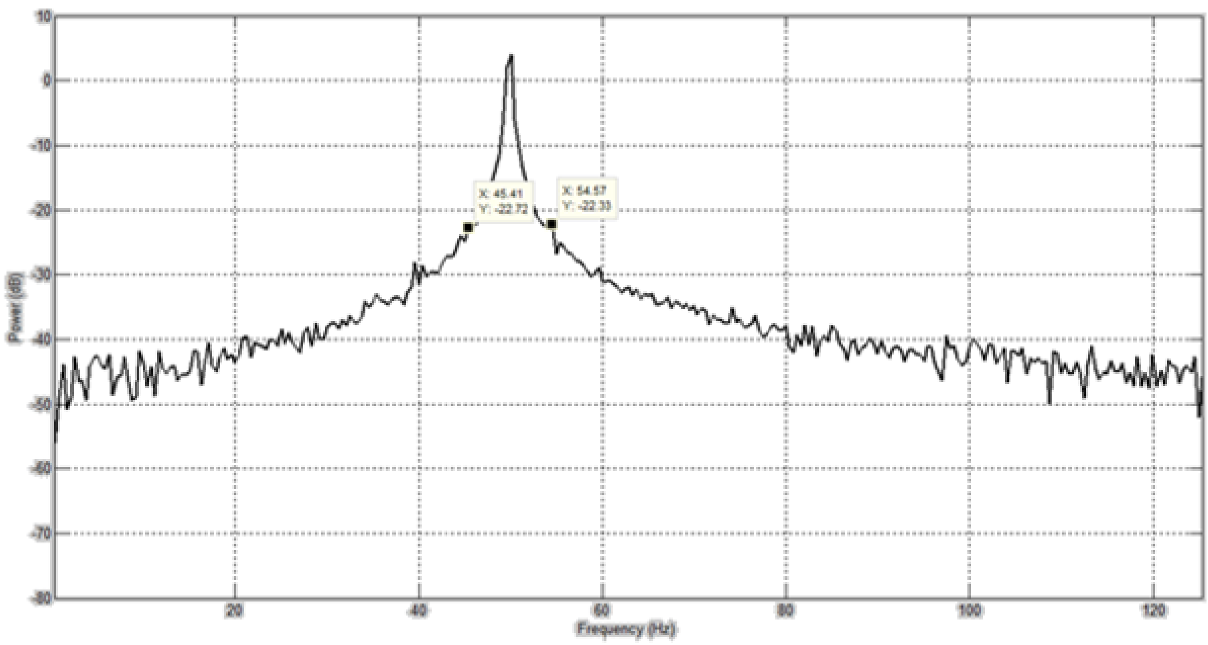

Fig 8: Plot for data obtained from faulted motor

2.7 BEARING OUTER RACE FAULT

The bearing mainly consists of the outer and inner race, the balls and cage which assure equidistance between the balls. The relationship of bearing vibration to the stator current spectra can be determined by the fact that air gap eccentricities produces anomalies in the air gap flux density. Since ball bearings support rotors, any bearing fault produces radial motion between rotor and stator of the machine. The mechanical displacement resulting from damaged bearing causes the machine air gap to vary in a manner that can be described by a combination of rotating eccentricities moving in both directions. Due to rotating frequencies, the vibrations generate stator currents at frequencies given as

$$f = f_1 \pm m\, f'$$

Where m=1,2,3,.. and f´ is one of the characteristic frequencies which are based upon bearing dimensions.

Load conditions	**Slip**	**LSB**	**USB**
No load	0.01	33	108

Table 4 : Expected fault frequencies for a given slip at a given load condition for bearing outer race faults

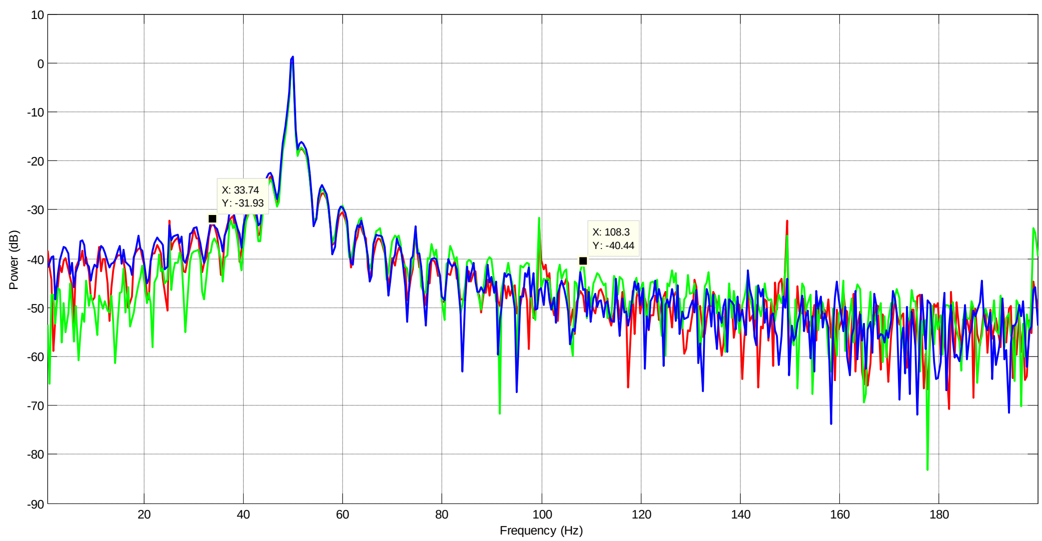

Fig 9: Plot for data obtained from faulted motor

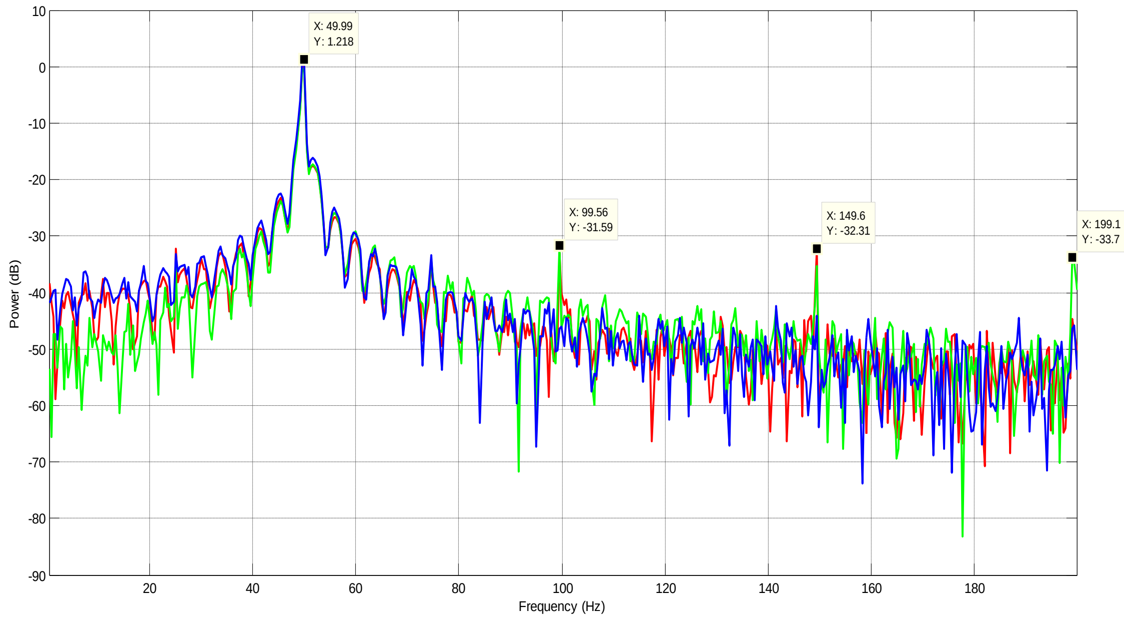

Fig 10: Plot for data obtained from healthy motor

The Power Spectrum Density of a faulty motor and healthy motor are plotted. The healthy motor shows only fundamental frequency with some harmonic components. It is free from all fault frequencies. The faulty motor shows noticeable fault frequencies, which are due to faulty bearings in motor. Thus by comparing both, bearing faults can be diagnosed easily.

CHAPTER 3

COMMUNICATION

3.1 GENERAL

With the increased demand for uptime and decreased tolerance for unplanned shutdowns, industrial facilities are under more pressure than ever to keep their electrical systems running properly. One of the chief problems is figuring out how to integrate data among multiple sites to ensure equipment runs properly without having to travel hundreds of miles per day. The reliability level has to be kept high though if an organization is responsible for multiple sites with umpteen amounts of resources. Remote monitoring can provide the necessary information to stay on top of equipment conditions and would report on equipment degradation issues.

Advances in networking hold the key, because they enable real-time system monitoring from a central location. Remote power monitoring systems perform the same functions as conventional systems only the location is different. They gather real-time statistical and historical data which may be outsourced to analyze and act on. This can be applied to customize load reduction strategies, help schedule the idle time of the processes around peak usage, compare utility rate structures, recommend predictive and corrective maintenance based on trends, and troubleshoot problems.

3.2 ARDUINO

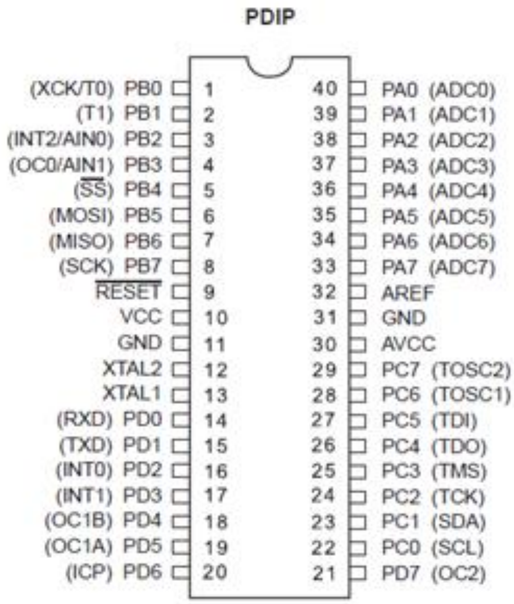

Fig 11: Pin configuration of ATMEGA 328

Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limits)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
Analog Input Pins	6
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
EEPROM	1 Kb
Clock Speed	16 MHz

Arduino has a number of facilities for communicating with a computer, another Arduino, or other microcontrollers. It has an advanced RISC architecture with 32Kb of In-system flash memory and up to 16 MIPS throughput at 16 MHz The ATmega328 provides UART TTL (5V) serial communication, which is available on digital pins 0 (RX) and 1 (TX). The RX and TX LEDs on the board will flash when data is being transmitted via the USB-to-serial chip and USB connection to the computer (but not for serial communication on pins 0 and 1).

3.3 GSM

Designed for global market, SIM900 is a quad-band GSM/GPRS engine that works on frequencies GSM 850MHz; EGSM 900MHz, DCS 1800MHz and PCS 1900MHz. SIM900 supports the GPRS coding schemes CS-1, CS-2, CS-3 and CS-4 and can search the 4 frequency bands automatically. With a tiny configuration of 24mm x 24mm x 3mm, SIM900 can meet almost all the space requirements in any smart phone, PDA and other mobile devices. The physical interface to the mobile application is a 68-pin SMT pad, which provides all hardware interfaces between the module and customers' boards.

It requires single supply voltage 3.4V - 4.5V. The transmitting power is limited to 2W at GSM 850 and EGSM 900 and 1W at DCS 1800 and PCS 1900 .The SIM900 is designed with power saving technique so that the current consumption is as low as 1.5mA in SLEEP mode. Its temperature range lies between -30°C to +80°C. It is integrated with the TCP/IP protocol; extended TCP/IP AT commands are developed for customers to use the TCP/IP protocol easily, which is very useful for those data transfer applications. SIM900 supports SIM card at 1.8V and 3V.

GSM SHIELD

Fig 12: GSM shield

The Arduino GSM Shield connects Arduino to the internet using the GPRS wireless network. Plugging this module onto Arduino board and a SIM card from an operator offering GPRS coverage can be used for communication. Its operating voltage is 5V which is supplied from the Arduino Board. The shield uses a radio modem M10 by Quectel and the GSM library has a large number of methods for communication with the shield. The shield uses digital pins 2 and 3 for software serial communication with the M10. Pin 2 is connected to the M10’s TX pin and pin 3 to its RX pin. The M10 is a Quad-band GSM/GPRS modem that works at 4 different frequencies. GPRS data downlink and uplink transfer speed maximum is 85.6 kbps. To interface with the cellular network, the board requires a SIM card provided by a network operator.

The shield contains a number of status LEDs:

- On: shows the Shield gets power.

- Status: turns on to when the modem is powered and data is being transferred to/from the GSM/GPRS network.
- Net: blinks when the modem is communicating with the radio network.

There are two small buttons on the shield. The button labeled "Reset" is tied to the Arduino reset pin. When pressed, it will restart the sketch. The button labeled "Power" is connected to the modem and will power the modem on and off.

CHAPTER 4

CONCLUSION

The common types of faults in induction motor are studied and various types of current based condition monitoring and fault diagnosis techniques are reviewed. A literature survey is presented to summarize the state of art techniques that are applicable to the methods proposed in the research. In all condition monitoring algorithms, base measurements are taken for a healthy motor at the time of commissioning. The fault algorithm monitors the magnitude of amplitude of fault frequencies and tracks changes in their amplitudes over time. Any significant change of the amplitudes indicates a developing fault. Experiments show that defects affect mainly two sidebands around fundamental frequency.

The logical next step after condition monitoring is fault diagnostics and automated communication of the type of fault to a remote device. A cost effective and efficient solution for this purpose with a help of Arduino microcontroller and GSM based communication module has been proposed. Arduino provides an open source programming platform wherein n number of libraries can be added by the user. Minimum power consumption, simple and clear programming language, cost efficiency, open source with extensible hardware and software are its key features. GSM (Global System for Mobile Communications), is a standard set developed by the European Telecommunications Standards Institute (ETSI) to describe protocols for second generation digital cellular networks used by mobile phones. The transmission power in the handset is limited to a maximum of 2 watts in GSM 850/900 and 1 watt in GSM 1800/1900. The GSM technology has a wide bandwidth and uses five bands of MHz frequency; 450, 850, 900, 1800 and 1900 MHz Those handsets can then switch between those frequencies automatically as needed, in order to maintain a network connection almost anywhere. The signals available with GSM service are efficient, meaning that a great deal of data can transmit across the frequency bands without reducing the effectiveness of the signals. GSM providers control a large share of the cellular market and therefore are able to provide a large variety of affordable services.

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APPENDIX

1. MATLAB CODE FOR CATEGORISATION OF FAULTS

```
clc;
clear all;
close all;
%----------------------------------------------------------------------
%The sampling Frequency
sampFreq = 20000;

%Create the time vector
t = 0:1/sampFreq:3;
amps =  [0.7 0.9 1.8 5 1.8 0.9 0.65];
freqs = [12 27 46 50 54 73 87];
% phase = [0.7854    1.5708    2.0944    2.6180    5.4978];
% phase = [pi pi pi pi pi]
%
windowtype = 'hann';
zeronum = 10;
%----------------------------------------------------------------------

%Create the signal
if length(amps) == length(freqs)
for iter = 1:length(amps)
if iter == 1
        y = amps(iter)*sin(2*pi.*t*freqs(iter));%+phase(iter);
else
        y = (amps(iter)*sin(2*pi.*t*freqs(iter))+y);%+phase(iter))+ y;
end
end
else
   disp('Error: amps and freqs must be the same length');
return
end
```

```
[windowzeropadamp freqwindowzeropad] = findFFT(y,'-sampFreq',sampFreq,'-
window',windowtype,'-zeropad',zeronum);
%%
legh_ = []; legt_ = {};

h_ = plot(freqwindowzeropad,windowzeropadamp,'Color',[0 .8 .5]);
legh_(end+1) = h_;
legt_{end+1} = 'Windowed Zeropad FFT';

%Create legend
leginfo_ = {'Orientation', 'vertical', 'Location', 'NorthEast'};
h_ = legend(gca,legh_,legt_,leginfo_{:});

ind = find(freqs == max(freqs));
xlim([0 freqs(ind)+5]);
xlabel('Frequency');
ylabel('Amplitude');

%find side bands

endsweep=49;

i=1;
max=-100;
while(freqwindowzeropad(i)<49)
if(windowzeropadamp(i)>max)
        max=windowzeropadamp(i);
        pos=i;
end
   i=i+1;
end
freq2=round(freqwindowzeropad(pos));
freq1=round(50+(50-freqwindowzeropad(pos)));

%Induction motor parameters

f1=50;
n1=1500;
```

```
n=1440;
s=(n1-n)/n1;
fr=(n/60);
p=4;
gearratio=1;
n1=(120*f1)/p;
Rtrfault=0;
Strfault=0;
innerrace=0;
outerrace=0;
ball=0;
cage=0;

%Fault classification

ser=serial('COM14','baudrate',9600);

%Broken rotor bar analysis

fBrokenBarUSB=(1+(2*s))*f1;
fBrokenBarLSB=(1-(2*s))*f1;

%Stator winding Fault analysis

fStatorWindingUSB=((1+((1/(p/2))*(1-s)))*f1);
fStatorWindingLSB=((1-((1/(p/2))*(1-s)))*f1);

%Bearing fault analysis

fo=0.4*8*fr;
fi=0.6*8*fr;
fb=4.8*fr;
fc=0.4*fr;
fBearinginnerUSB=abs(f1+fi);
fBearinginnerLSB=abs(f1-fi);
fBearingouterUSB=abs(f1+fo);
fBearingouterLSB=abs(f1-fo);
fBallUSB=abs(f1+fb);
fBallLSB=abs(f1-fb);
```

```
fCageUSB=abs(f1+fc);
fCageLSB=abs(f1-fc);

%Gear fault

frot=(f1/(gearratio*p));
fGearUSB=abs(f1+frot);
fGearLSB=abs(f1-frot);

if((fBrokenBarUSB==freq1)&&(fBrokenBarLSB==freq2))
%broken rotor bar fault detected
   fopen(ser);
   file1=fread(ser);
   fwrite(ser,'a');
   fclose(ser);
   Rtrfault=1;

elseif((fStatorWindingUSB==freq1)&&(fStatorWindingLSB==freq2))
%Stator winding fault detected
      fopen(ser);
      file2=fread(ser);
      fwrite(ser,'b');
      fclose(ser);
      Strfault=1;

elseif((fBearinginnerUSB==freq1)&&(fBearinginnerLSB==freq2))
%inner race fault
   fopen(ser);
   file3=fread(ser);
   fwrite(ser,'c');
   fclose(ser);
   innerrace=1;

elseif((fBearingouterUSB==freq1)&&(fBearingouterLSB==freq2))
%outer race fault
   fopen(ser);
   file4=fread(ser);
   fwrite(ser,'d');
   fclose(ser);
```

```
   innerrace=1;

elseif((fBallUSB==freq1)&&(fBallLSB==freq2))
%Ball fault
   fopen(ser);
   file5=fread(ser);
   fwrite(ser,'e');
   fclose(ser);
   ball=1;

elseif((fCageUSB==freq1)&&(fCageLSB==freq2))
%Cage fault
   fopen(ser);
   file6=fread(ser);
   fwrite(ser,'f');
   fclose(ser);
   cage=1;

elseif((fGearUSB==freq1)&&(fGearLSB==freq2))
%Gear fault
   fopen(ser);
   file7=fread(ser);
   fwrite(ser,'g');
   fclose(ser);
   outerrace=1;

end
```

2. ARDUINO CODE FOR INTERFACING WITH COMMUNICATING GSM MODULE

```
#include "sms.h"

#include "SIM900.h"

#include <SoftwareSerial.h>
```

```
SMSGSM sms;
int i=0;
boolean started=false;

intincomingByte=0;
void setup()
{
Serial.begin(9600);



if (gsm.begin(2400)){
Serial.println("\n GSM status=READY");
started=true;
  }
elseSerial.println("\n GSM status=IDLE");
}
void loop()
{
if (Serial.available() > 0) {
incomingByte = Serial.read();

if (incomingByte == 97)
```

```
  {
if (sms.SendSMS("9629312846", "broken rotor bar fault detected!!"))
Serial.println("\nSMS sent OK");
  }
else if(incomingByte == 98)
 {
if (sms.SendSMS("9629312846", "Stator winding fault detected!!"))
Serial.println("\nSMS sent OK");
  }
else if(incomingByte == 99)
 {
if (sms.SendSMS("9629312846", "Inner race fault detected!!"))
Serial.println("\nSMS sent OK");
  }
else if(incomingByte == 100)
 {
if (sms.SendSMS("9629312846", "outer race fault detected!!"))
Serial.println("\nSMS sent OK");
  }
else if(incomingByte == 101)
 {
if (sms.SendSMS("9629312846", "ball bearing fault detected!!"))
```

```
Serial.println("\nSMS sent OK");
   }
else if(incomingByte == 102)
  {
if (sms.SendSMS("9629312846", "Cage fault detected!!"))
Serial.println("\nSMS sent OK");
   }
else if(incomingByte == 103)
  {
if (sms.SendSMS("9629312846", "Gear fault detected!!"))
Serial.println("\nSMS sent OK");
   }
 }
}
```

3. ARDUINO CODE FOR RMS CURRENT COMPUTATION

```
#include "EmonLib.h"
#if defined(ARDUINO) && ARDUINO >= 100
#include "Arduino.h"
#else
```

```
#include "WProgram.h"
#endif


void EnergyMonitor::current(int _inPinI, double _ICAL)
{
  inPinI = _inPinI;
  ICAL = _ICAL;
}
double EnergyMonitor::calcIrms(int NUMBER_OF_SAMPLES)
{
int SUPPLYVOLTAGE = readVcc();
unsigned long start = millis();
sampleI=0;
filteredI=0;
 for (int n = 0; n < NUMBER_OF_SAMPLES; n++)
 {
   lastSampleI = sampleI;
   sampleI = analogRead(inPinI);
   lastFilteredI = filteredI;
```

```
    filteredI = 0.996*(lastFilteredI+sampleI-lastSampleI);
    // Root-mean-square method current
    // 1) square current values
    sqI = filteredI * filteredI;
    // 2) sum
    sumI += sqI;
  }
//Serial.println(millis()-start);
  double I_RATIO = ICAL *((SUPPLYVOLTAGE/1000.0) / 1023.0);
  Irms = I_RATIO * sqrt(sumI / NUMBER_OF_SAMPLES);
  //Reset accumulators
  sumI = 0;
//--------------------------------------------------------------------------------------
  return Irms;
}
```